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Polishing Mineral Specimens by the Use of an Optical Polishing Machine

Wilbur J. Guay

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Wilbur J. Guay

A Thesis

Submitted to the Department of Mineral Dressing

in Partial Fulfillment

of the Requirements for the Degree

of

Bachelor of Science in Metallurgical Engineering

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POLISHING MINERAL SPECIMENS
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INTRODUCTION

The Problem

The problem in this investigation was to determine if mineral specimens mounted in bakelite, or lucite, could be polished for microscopic examination by the use of an optical polishing machine, and if this method would cut down the length of time required to polish specimens by the methods now in use.

Acknowledgements

The writer wishes to express his appreciation to Mr. Herman Neibauer for his assistance and suggestions, and in particular to Dr. S.R.B. Cooke, under whose direction this investigation was carried out.

Practical Considerations

The Mechanics of Grinding and Polishing

Abrasives on a metal lap may be either fixed or rolling, and the results obtained from each are different. Rolling abrasives are loose on the lap and free to roll. They are used for coarse grinding, because they cut deeper, by fracturing and fissuring the mineral surface, and do a rapid job. However, they are not used for fine grinding and polishing. The rough action of rolling abrasives is what causes pits in a mineral. A fixed abrasive is fixed in the sense that it cannot be washed off the lap by a stream of liquid. This type of abrasive is necessary for fine grinding and polishing. Fixed abrasives are not permanently imbedded in the lap surface, because they may be rolled during grinding and polishing, but they are relatively stable. The action of a fixed abrasive is one of cutting or planing, and not of fracturing. This planing action is what causes scratches on a specimen. A small amount of abrasive is necessary for fixed abrasive grinding or polishing, as well as a small amount of lubricant. The lubricant is important in that it should be sufficient to reduce friction and keep the specimen from plucking, and yet not be in sufficient quantity to loosen the abrasive. Abrasive action is reduced by heavy oils.

An abrasive film, used in polishing, is a paste of equal parts of abrasive and kerosene. When the lap shows a thin film of abrasive with criss-cross lines, one-eighth to one-quarter inch wide, the lap has the proper film. An abrasive film on a lap surface has properties intermediate between those of the fixed and the rolling abrasive. In the film each particle is kept from rapid rolling by the adjacent particles and by adhesion of the lubricant and particles. The greater quantity of abrading particles in an abrasive film increases the speed of abrasion greatly.(1)*

John W. Vanderwilt(2) says that abrasives coarser than 0.01 mm. cause subsurface shattering beneath the bottoms of the deepest pits and scratches.

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*Numbers refer to bibliography pp.30 - 31

Preston[3] has shown by direct measurements that to polish glass, beginning with a matte surface with pits three wavelengths of light deep, it was necessary to remove from the surface a layer six to ten wavelengths in thickness to get to the bottom of fissures or flaws that extend below the pits. These flaws or fissures have also been observed in transparent minerals. This fracturing causes plucking or pulling out of the fragments during abrasion, and is the reason why large pits may appear near the end of a polishing operation. Vanderwilt says that if the specimen is obtained with a diamond saw that subsurface shattering is avoided, and that if a fine abrasive is used from this point on, despite its slow cutting power, a satisfactory polish will be secured in less time. Dr. S.R.B. Cooke of the Montana School of Mines, under whom this work was carried out, says that it is his experience with diamond saws that they will also cause subsurface shattering, and it is not necessarily avoided by their use.

There are two theories concerning the actual mechanism of polishing[2]. The first theory is that polishing is abrasion by hard cutting grains, so fine that the scratches are microscopic or submicroscopic in size. The second theory is the amorphous film theory, originated by Bielby, which postulates that a thin surface layer is liquefied by the fine, but not necessarily hard, polishing powders. This liquid layer, before it solidifies, is supposed to be drawn by surface tension into a smooth surface which constitutes polish. The skin so formed is thought to be amorphous, and is supposed to be capable of filling, or bridging over, and thus concealing pits or other features. Physical tests, such as x-rays, polarized light, color, hardness, solubility, etc. fail to reveal the existence of the amorphous film. Later work using electron diffraction seems to support the theory. One argument supporting the theory that polishing is identical with abrasion is the fact that the polishing media must be essentially as hard, or harder, than the surface being polished. Diamond is invariably polished with diamond dust, other substances not being effective.

Various Kinds of Laps

Metal laps produce a minimum of relief between hard and soft minerals because of the high resistance, or unwillingness of the metal surfaces to yield. This is not so in cloth laps because they yield and allow the soft minerals to be ground faster, thus producing relief between hard and soft minerals. A pitch lap has different properties according to how long it was heated. The longer pitch is heated, the harder it will be upon cooling. A straight pitch lap which is not heated long enough will allow the specimens to sink into it, and tear its surface because of its softness. One which is heated long enough to produce a hard surface will scratch the specimens. This problem is solved by heating the pitch on a metal lap, and covering it while molten with cloth, which absorbs the pitch. If cooled soon enough and the pitch hardened to an intermediate stage, it will form a lap which will be of the right hardness when the cloth is completely saturated with pitch. This type of lap will not scratch the minerals, or be torn by them. It is also capable of fixing the abrasive in a manner identical with the action of a soft metal lap.

Present Polishing Techniques

The most common method of polishing mineral specimens at present is by the use of a Graton-Vanderwilt type of machine, using metal laps. In this type of machine the specimens are held face down on the lap, and revolve in one direction, while the lap is revolving in the opposite direction. Rolling abrasives are used in initial grinding of the specimens, usually on a copper lap. Final polishing is done on a lead lap using a fixed abrasive. This method has two major disadvantages: (1) It requires an excessively long time, usually about ten hours, to polish a set of specimens; (2) It requires a long time to acquire the technique of using the machine. A method is described by J. Osborn Fuller[1] of polishing specimens on a Graton-Vanderwilt machine, using a film of abrasive. The chief difficulty with this type of polishing, as the author sees it, is in obtaining the correct film to be used. Fuller claims it takes from ten to sixty minutes to grind and polish the specimens. This would be a remarkable advantage for this method of polishing specimens. Another advantage he claims is that only two different sized abrasives are used.

Cloth laps are used to polish specimens, but are open to objections. One objection is that soft minerals polish much more readily, and relief is developed between hard and soft minerals. Another is that there is a great tendency for plucking. Cloth laps are more generally used for polishing metals than for minerals.

A recent article[4] describes the polishing of minerals on metal laps by using a machine which is similar to the optical machine used in this investigation. The specimens are held in vertical sleeves with enough room to allow them to revolve in the sleeve, and are held against a revolving horizontal lap by means of springs in the sleeves. The specimens are then subjected to three kinds of motion. The lap is driven by a motor drive, and revolves. The entire head which contains the sleeves revolves by the friction of the specimens on the lap, and each specimen revolves in its own sleeve by friction. Another scheme is also described wherein the entire head is driven by an eccentric. This machine cuts down the time considerably, and produces a surface which is free from relief. A method of polishing specimens by hand on a paper lap is also described.

Requirements of a Good Polished Surface

The chief requisites of a good surface are: an abscence of pits and scratches, a constant angle of reflection, and freedom of relief between hard and soft minerals. Pits and scratches are bad because they are annoying to the eye, obscure a part of the field, often acting selectively by removing much or all of a given constituent, and introducing modifying influences on color, hardness, microchemical behaviour, etc. A constant angle of reflection is necessary to produce even illumination, reliability of color, and good visibility. Excessive relief causes an endless change of focus, prevents hard and soft mineralsfrom being in good focus at the same time, except at low magnification, and obscures as a black rim, the contact between hard and soft grains, yet this contact is a critical phase, being far more instructive as a rule than the middle of the grains, and ought to be available for the most careful investigation.[2]

Properties of Abrasives

Carborundum, a manufactured silicon carbide, and alundum, a natural or prepared oxide of aluminum, are both used for coarse grinding, and are very hard abrasives. Alundum is also used for intermediate grinding, and a softer grade of prepared alumina is used for polishing. Rouge(red iron oxide), magnesia, and chromic oxide are all used for polishing. Chromic oxide and rouge are used on hard minerals, and magnesia is used on soft minerals. Abrasives are sized either by elutriation or sedimentation(5, 6,7,8,). Magnesia has to be kept fresh because it changes its properties upon standing. The maximum size of No. 600 carborundum is 0.054 mm.[8], but has an average size of about 0.009 to 0.027 mm. The maximum size of No. 600 alundum is 0.075 mm., but the average size is from 0.04 to 0.01 mm.

Use of Polished Specimens

Polished specimens are used by geologists to determine the structure and the origin of the ore. They may be used by the mineral dressing engineer to estimate the composition of a mineral, or ground mineral product, by counting the grains, or they may be used to determine the characteristics of the ore. They are also used to determine the size of liberation in crushed and ground products.

THE INVESTIGATION

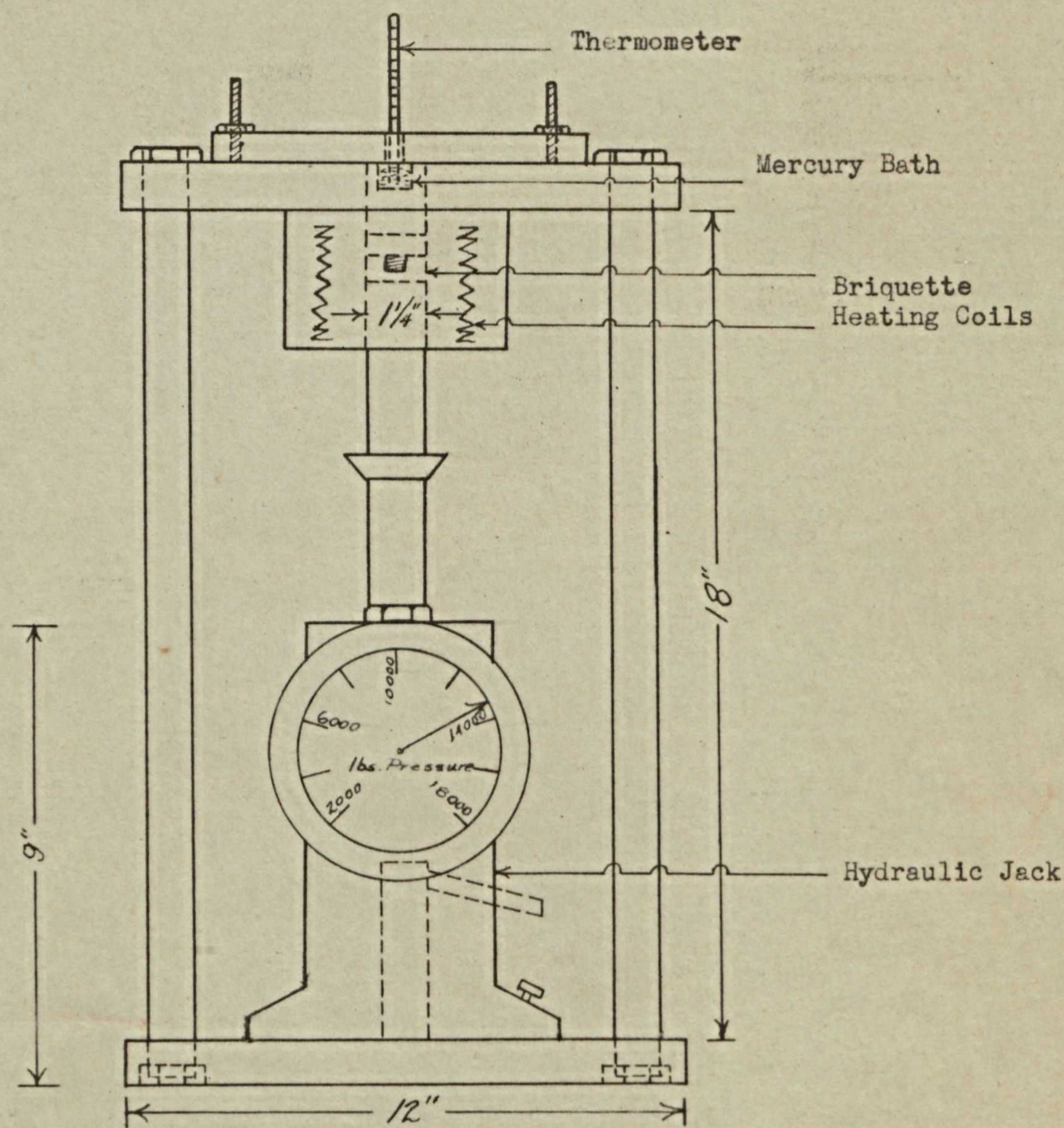
The Method of Mounting Specimens

The specimens were mounted in bakelite and lucite briquettes. The briquettes were prepared by pressure heat molding in a special molding press. Plate I shows the essential parts of the press. Pressure is applied by a hydraulic jack, and the bakelite or lucite is compressed, and then melted by electrically heated resistance coils. The briquettes formed are in the shape of a small cylinder as shown in Plate II-A. The bakelite is pressed at 10,000 to 12,000 lbs. pressure, at a temperature of 60 to 70 degrees C. and then cooled, while lucite is pressed at 4,000 to 6,000 lbs. pressure, at a temperature of 100 degrees C. and then cooled. Bakelite is a phenolic resin, and lucite is a thermoplastic material, methyl crylate.

For one of the specimen holders, which is to be described later, it was necessary to have a threaded hole, one-quarter inch deep, in the back of the briquette. A steel cylinder, of the same diameter as the mold, and about one inch thick, with a threaded screw projecting from its center was prepared. This is shown in Plate II-B. This was placed in the mold with the screw facing downward into the bakelite or lucite as shown in Plate I, and thus formed the threaded hole in the back of the briquette. The screw and the briquette were removed from the press together, and were separated by simply unscrewing the two.

In preparing a specimen the mineral is ground down to a flat surface first, usually by rubbing the specimen on a glass plate which has a paste of abrasive and water on it. The abrasive used is either coarse alundum or carborundum. The specimen is then placed in the mold face down, followed

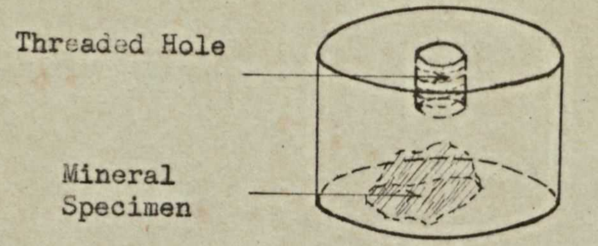
PLATE I



BRIQUETTING PRESS

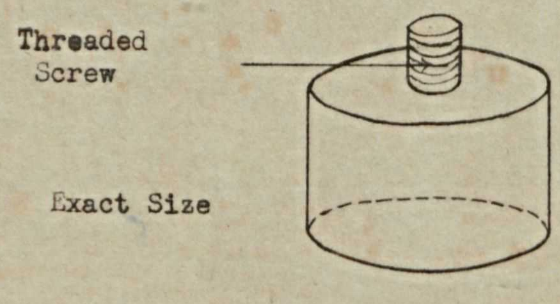
Scale 1/4"=1"

A.



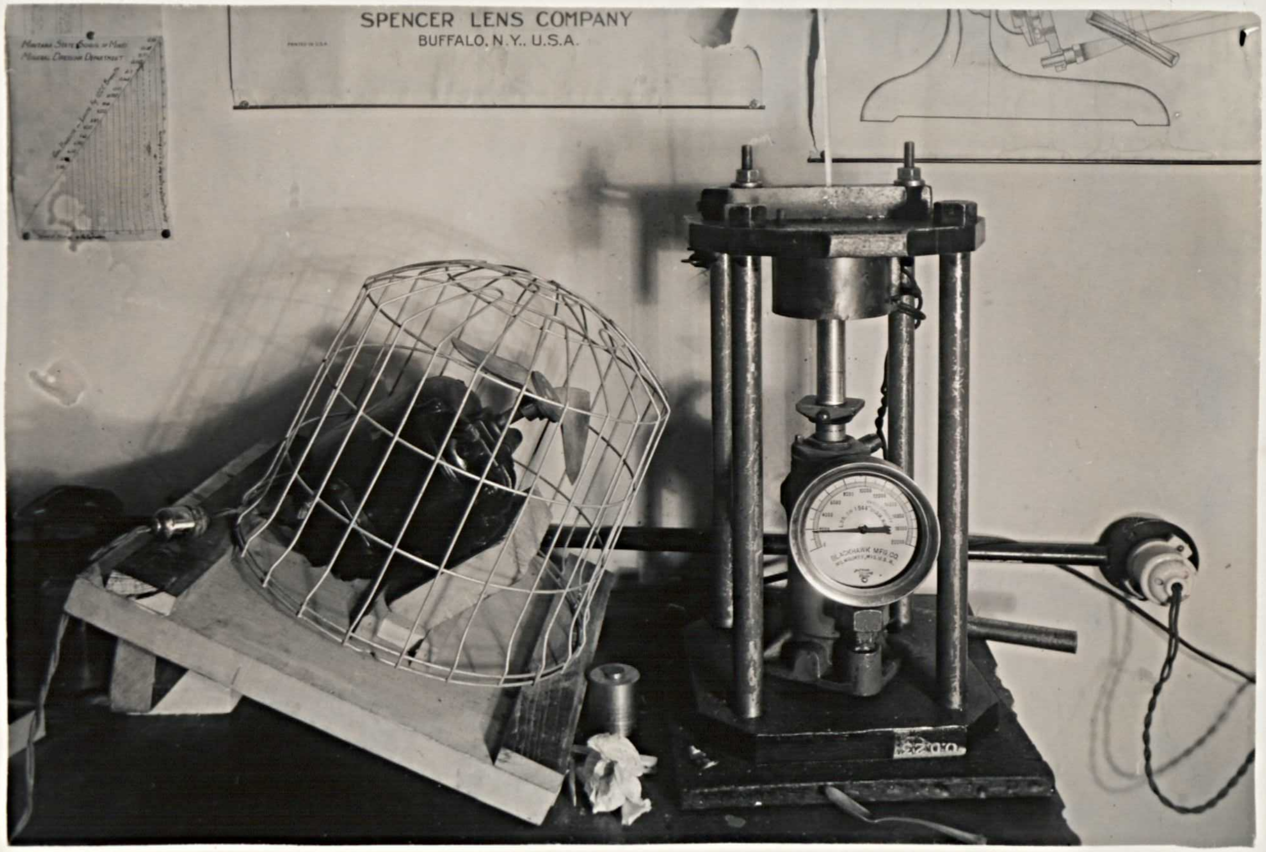
Bakelite or Lucite Mount
Exact Size

B.



Steel Cylinder
Used for
Molding Briquettes

Figure 1

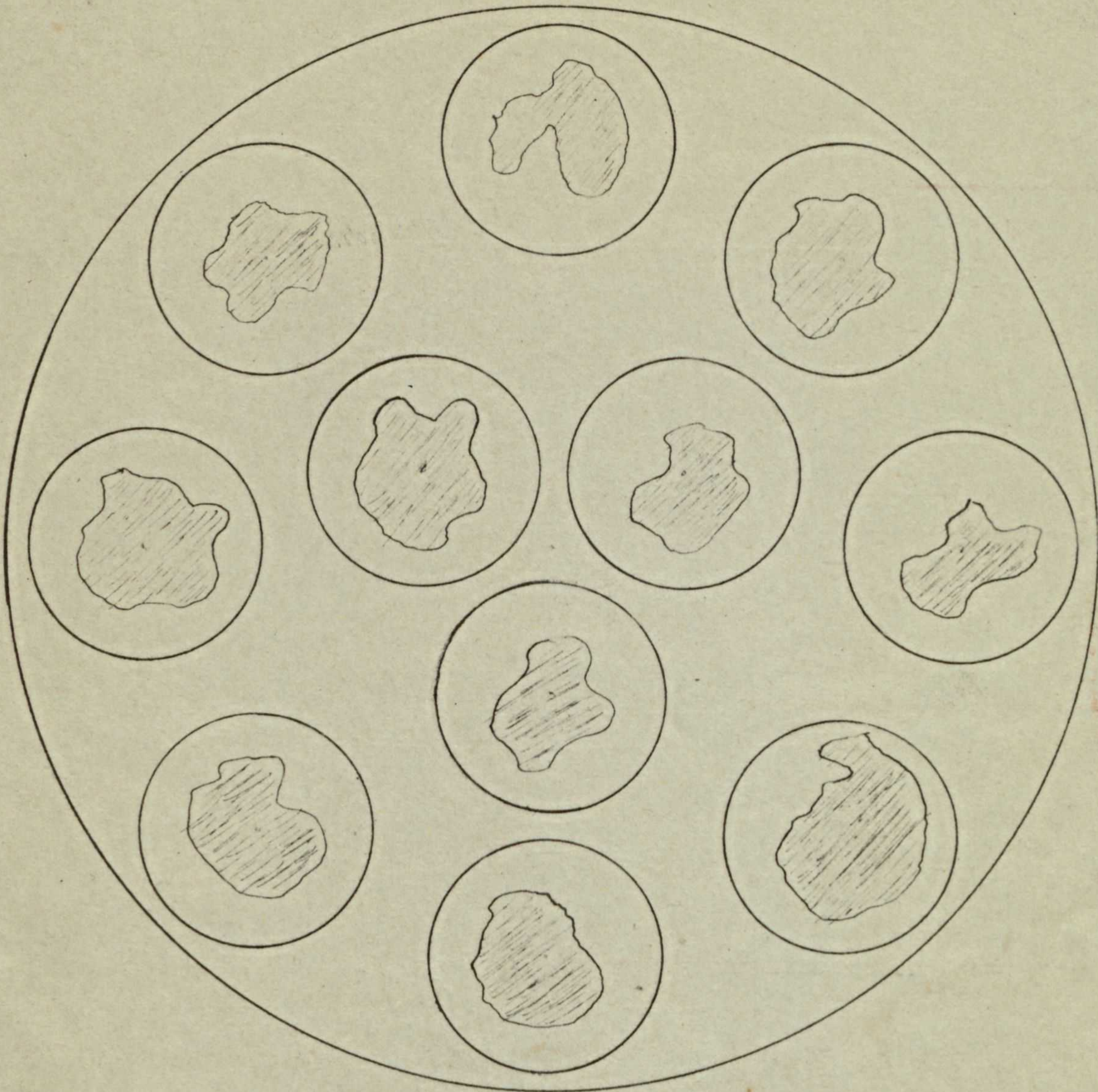


Briquetting Press and Fan

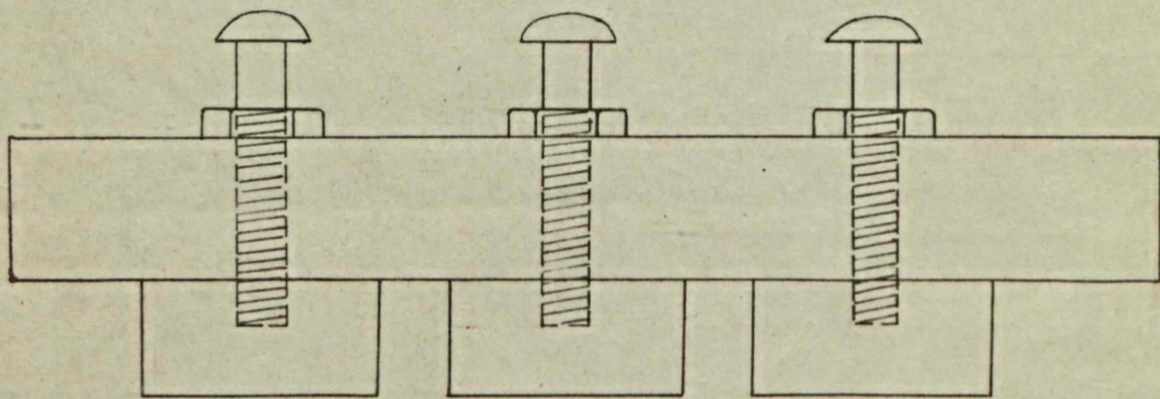
by the bakelite or lucite, and finally the steel cylinder. The steel cylinder may have a screw projecting downward from it as already described, or may be flat, depending on whether it is necessary to have a threaded hole in the back of the briquette or not. A picture of the briquetting press with a fan to cool the hot briquettes after fusion is shown in Figure 1. Ground products are mounted by mixing them with an equal amount of lucite, pouring this into the mold, then pouring the rest of the lucite on top of this. Pressure and heat are then applied, and a briquette with the ground particles dispersed on its surface is obtained. Bakelite is not generally used on ground products. A method of mounting friable materials is described by C.S. Ross[9] in which the pores of the mineral are filled with bakelite varnish.

Description of Specimen Holders Used

The first type of holder prepared consisted of a flat steel disk, six inches in diameter, and three quarters of an inch thick. Eleven holes were drilled through the disk and tapped. Eight of the holes were evenly spaced around the outside of the disk, at three quarters of an inch from the edge of the disk. The outer three holes were drilled around the center of the disk, at a distance of seven eighths of an inch from the center, and spaced sixty degrees apart. One-quarter inch holes, with twenty threads to the inch, were tapped, and bolts to fit these holes were screwed through the back of the plate and into the backs of the briquettes, which were made for this purpose as previously described. This holder is shown in both Plate III and Figure 2. The nuts on the top of the plate were tightened to hold the bolts solid, and prevent them from twisting



Bottom View

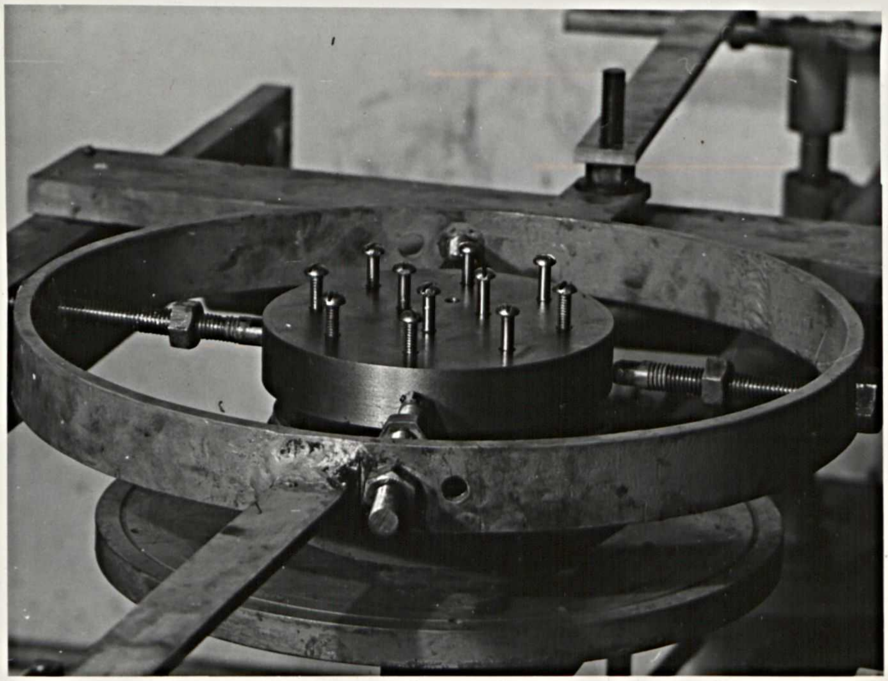


Side View

Specimen Holder
Exact Size

when the holder was placed in the polishing machine.

Figure 2

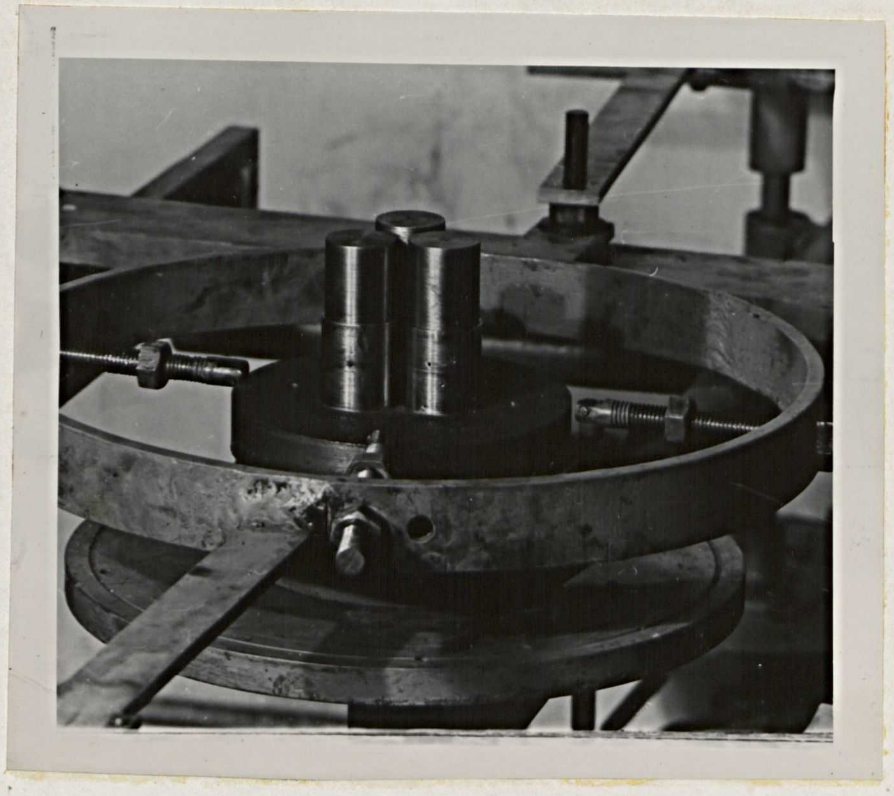


Specimen Holder

in Place in the Machine

The second type of holder is shown in figures 3 and 4. In this type of holder, flat backed briquettes are used, and the specimens are free to rock slightly in the brass tubes. The disk, as before, is made of steel. Steel cylinders which are tapered to a point at the bottom are placed in the brass tubes and their full weight rests on the specimens.

Figure 3



Specimen Holder in Place in the Machine

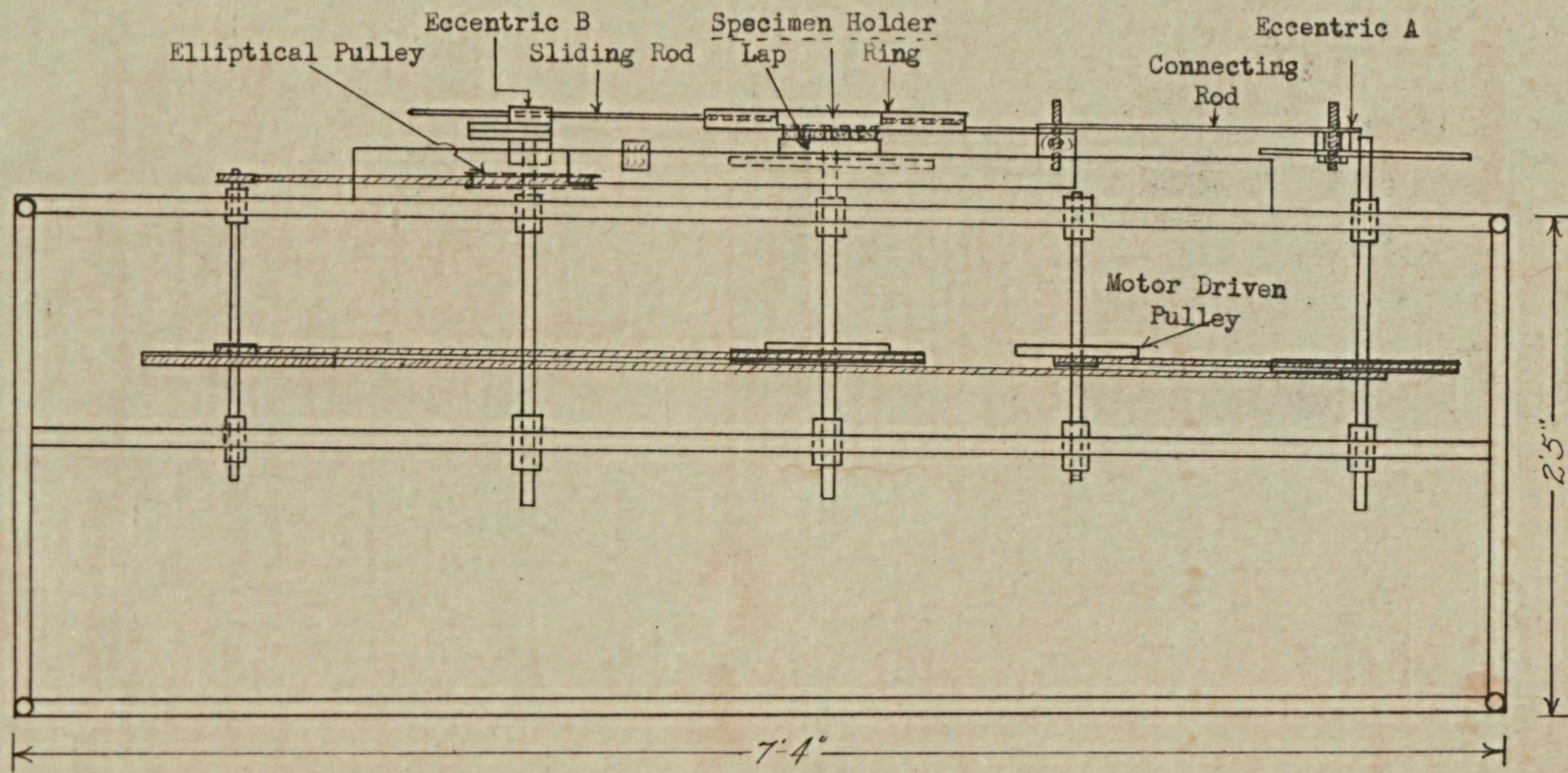
Figure 4

Bottom View of the Same Holder

Description of the Optical Polishing Machine

The term "optical polishing machine" means a machine that is used to polish optical ware, such as lenses and mirrors, which for certain types of work have to have a very high degree of polish. In this type of machine the specimens are held face down on the lap, and revolve in the same direction as the lap, only much slower, and with a jerking motion. The lap however runs smoothly. This rotary motion is accompanied by a backward and forward motion over the lap, together with a side to side motion at right angles to this across the lap. By producing all these different types of motion at once, there is no tendency for the lap to wear unevenly, or for the specimens to be ground unevenly. In the Graton-Vanderwilt machine the specimens keep revolving in the same path, and tend to wear a path in the lap, and thus produce an uneven or curved surface on the specimen which is very undesirable. This would only occur upon excessive wear, but the tendency is nevertheless present. The machine, as shown in Figure 5, is run by a system of pulleys and belts, driven by a Montgomery Ward capacitator motor. This is a 1/3 H.P. motor operating at 110 to 220 volts, 60 cycles, and at a speed of 350 rpm. The specimens are moved bacward and forward over the lap by the action of an eccentric A (Plate IV). This eccentric is connected by means of a connecting rod to a large fifteen inch ring, which is at the very top of the machine, shown in both Figure 5 and PlateIV. Bolts project through the sides of this ring, and almost touch the specimen holder, and cause it to revolve slowly. With each stroke the holder is revolved with a slight jerk, due to the inertia of the revolving lap. The length of the stroke can be regulated by changing the eccentric. The side to side motion is accomplished by a bearing set on an eccentric B (Plate IV), in which a rod extending backward from the previously mentioned ring slides back and forth. As the eccentric revolves the rod moves from side to side, and transmits this motion to the specimen holder. The length of this stroke may be regulated by changing the eccentric. As seen from both Figure 5 and Plate IV, the eccentric B is set on an elliptical pulley. This pulley was not used in the present investigation. In optical polishing, however, it causes an acceleration of the side to side motion at the center of the lap, and a slowing down of this motion near the edges of the lap. This causes a more even grinding of the surface to be polished by reducing its time of residence at any one place. The lap revolves at 2.4 rpm, and the specimen holder at 1.3 rpm. There are 85 backward and forward strokes per minute, and ten side to side strokes per minute. These were all carefully regulated by calculating the correct pulley diameters to be used when the machine was designed. This particular machine was designed and built by Dr. S.R.B. Cooke, and does not represent a commercial model machine, although similar in principle to many used.

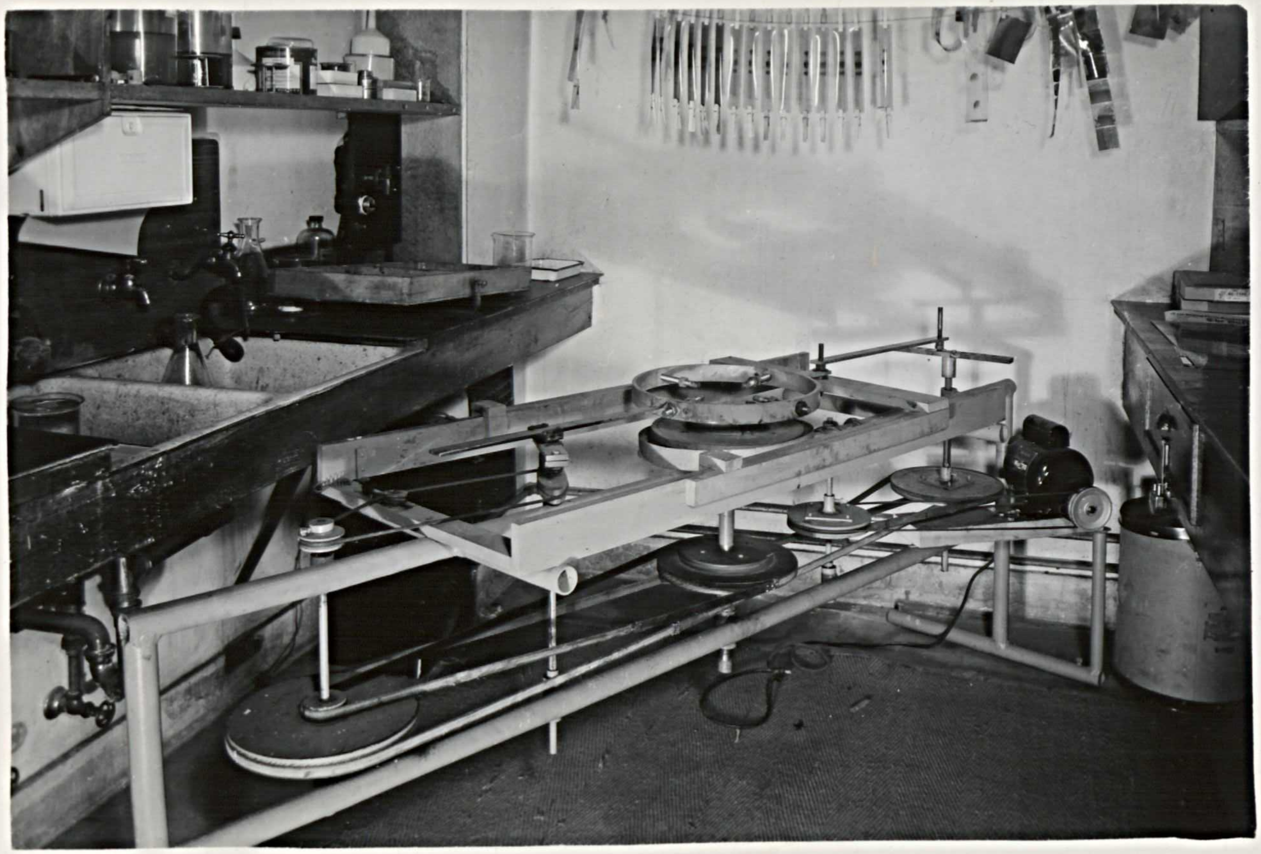
PLATE IV



OPTICAL POLISHING MACHINE

Scale 3/32" = 1"

Figure 5



Optical Polishing Machine

Grinding and Polishing Procedure

First Method

In the first attempt at polishing, eleven briquettes with holes in the back were prepared, and were used with the holder shown in Plate III. Both bakelite and lucite briquettes were prepared. The lucite gave a good threaded hole in which the threads were intact, but the bakelite tended to crumble, and the threads did not hold together well. The bakelite briquettes were prepared at temperatures ranging from fifty degrees C. to one hundred degrees C., in an attempt to discover if the amount of curing had any effect on this crumbling, but the results at different temperatures were about the same. However, coarse bakelite held together better, and formed a more stable thread than the minus one hundred mesh bakelite. When removed from the press the briquettes had rough edges which had to be removed. This was done by first grinding them dry on an emery wheel, and then with No. 600 carborundum for about five minutes on a glass plate with water. The briquettes were of varying thicknesses, and had to be levelled up in approximately the same plane when screwed onto the holders. This was done by adjusting the screws. The faces of the briquettes did not form a true plane however, because the holes through the plate were not perpendicular to the plane of the plate. The surfaces of these briqettes had to be levelled up by hand grinding them for one hour on a wet glass plate, using No. 200 carborundum. This was followed by an hour of grinding in the same manner, using No. 600 carborundum to help reduce the rough surface produced from the previous operation. The next step was to place the holder in the machine. The holder in place in the machine is shown in Figure 2. A six-inch cast-iron lap, with shallow V-shaped grooves, arranged in a checkerboard pattern, and spaced one inch apart was used. The grooves are necessary to hold the abrasive during coarse and intermediate grinding. The specimens were first ground with No. 600 carborundum for about five hours to reduce all coarse pits and scratches caused from the NO. 200 carborundum. They were further ground for two hours with No. 600 alundum, and final grinding was for two hours using minus 2.5 micron alundum.

A pitch lap using a six-inch cast-iron plate with broadcloth for a binder was next prepared. The specimens were then polished for four hours on this lap with polishing alumina. At the end of this time it could be seen with the naked eye that only the harder minerals were polished, and further examination under the microscope revealed that most of these were badly scratched and pitted. The specimens were then reground with minus 2.5 micron alundum, using the pitch lap instead of the metal lap. This changed the grinding action from that of a rolling abrasive to that of a fixed abrasive. The specimens were ground for an hour and a half and then polished for four hours with alumina, and finally examined under the microscope. Some of the softer minerals still showed pits and scratches, and were polished for an additional two hours with rouge. This produced little change however, and the polishing was, for all practical purposes, completed. In allpolishing and grinding operations water was used as the lubricant. It was added to the lap by means of an eyedropper from time to time. Figures 6 to 15 inclusive show the results of this work. The minerals present are indicated. Black spots in all of the pictures indicate pits. One specimen, pyrrhotite, failed to take a polish, and was not photographed.

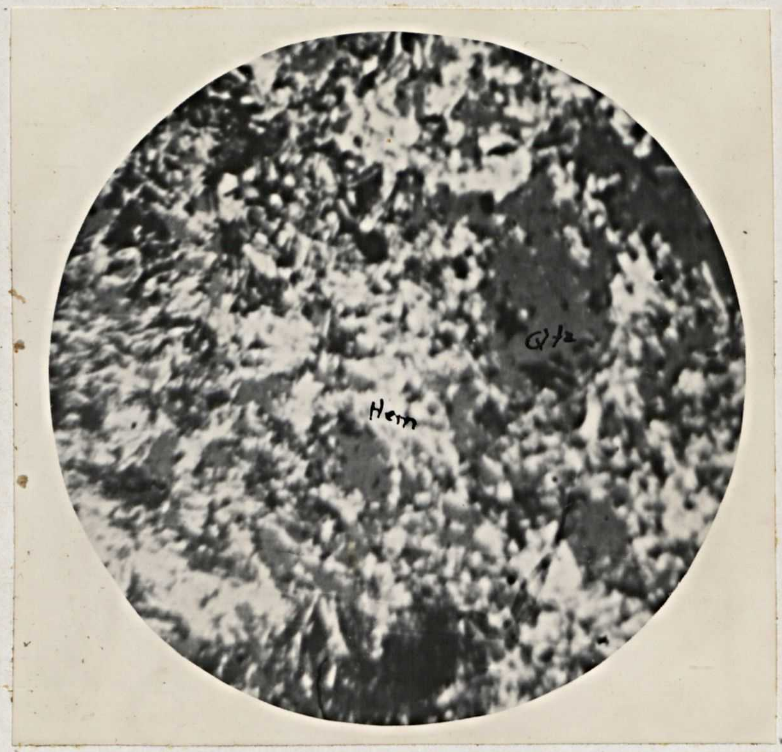
Figure 6

Pyrite, Sphalerite, and Quartz

Figure 7

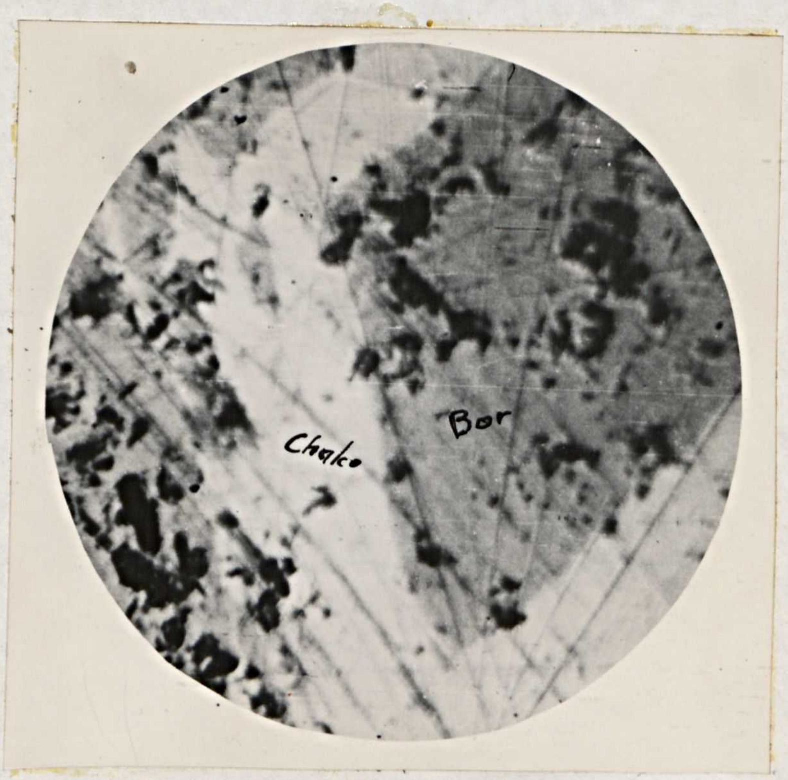
Hubnerite and Quartz

Figure 8



Hematite and Quartz

Figure 9



Bornite and Chalcopyrite

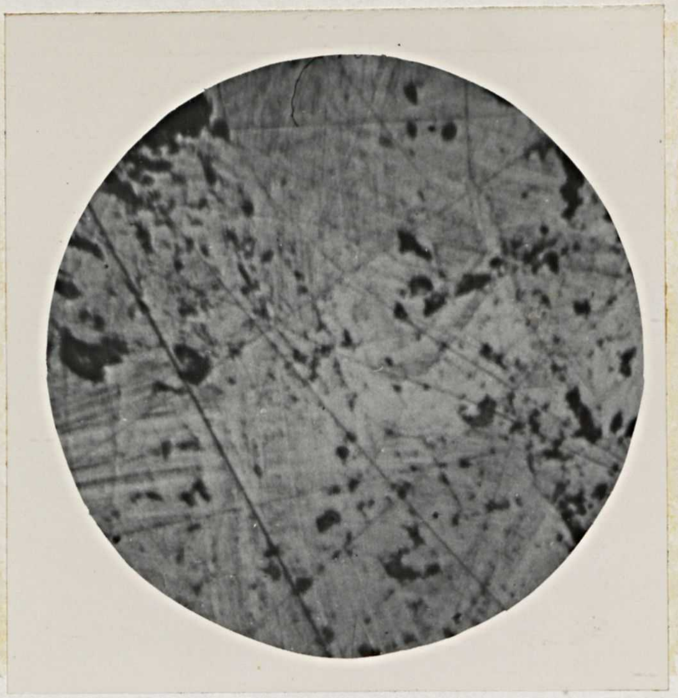
Figure 10

Chromite and Serpentine

Figure 11

Sphalerite

Figure 12



Chalcopyrite

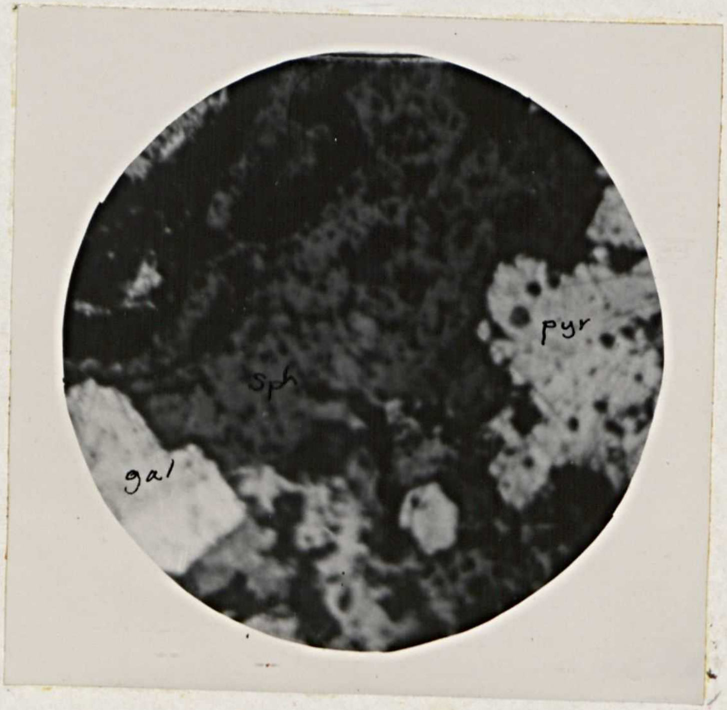
Figure 13

Arseno-pyrite and Quartz

Figure 14

Pyrite and Quartz

Figure 15



Galena, Pyrite, and Sphalerite

Second Method

Since it took so long to reduce the specimens to a level plane, and as it required a special threaded briquette in the first method used, it was decided to use the type of holder shown in Figures 3 and 4. The specimens were mounted, ground on the emery wheel, then ground by hand for about five minutes using No. 600 carborundum. The specimens were placed in the holder, which was in turn put into the machine. They were then ground with No. 600 carborundum for 45 minutes. Secondary grinding was for an hour and a half with No. 600 alundum. Final grinding was for an hour and half with minus 2.5 micron alundum. The specimens were then put on the previously mentioned six-inch pitch lap, and polished with alumina. After a few minutes however the cloth tore. This was due to the fact that at the end of every backward and forward stroke, the specimen holder projected over the edge of the lap and tipped. As the holder righted itself on the reverse stroke, its edge caught on the edge of the lap and tore the cloth.

It was therefore decided to use a ten inch lap, on which the holder would not go over the edge of the lap. A wooden lap to hold the pitch was first tried, but the wood could not be heated for obvious reasons. It was therefore decided to melt the pitch in a beaker, put the cloth in it, saturate it with pitch, and then attempt to spread the wet cloth over the lap. As soon as the pitch was exposed to the cool air, however, it began to solidify, and made a sticky, gummy, mess. It was impossible to put it on the lap in this manner, and the idea of using a wooden lap was abondoned.

A ten inch cast-iron lap was then made up as described on page four, using broadcloth as the binder. The specimens were polished on this lap using polishing alumina. After about an hour of polishing, the cloth tore again. This was due to the fact that the edges of the iron lap wore off the pitch right away, commenced to wear the cloth, and finally tore it. The wearing of the lap by the iron is much more severe than the wearing due to the briquettes when using the other type of holder.

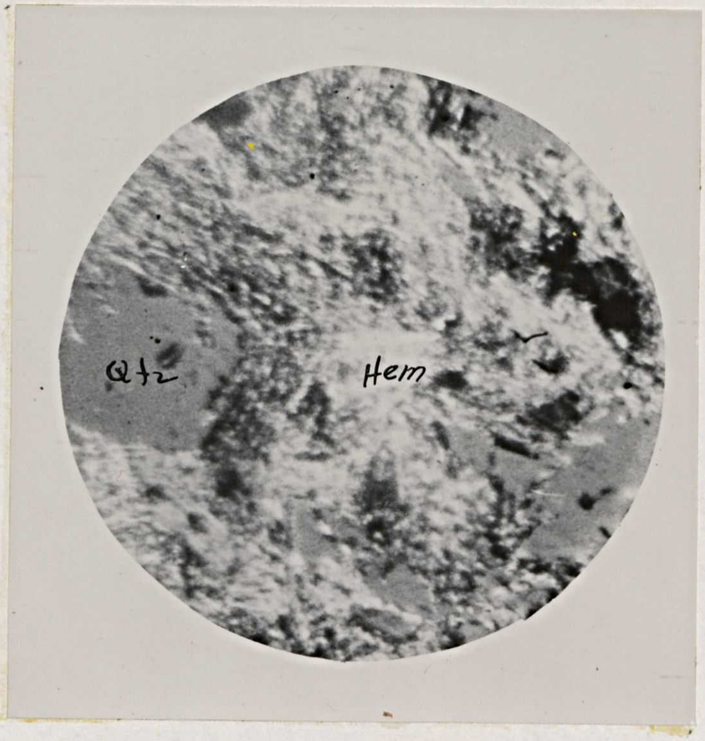
The next thing to be tried was a heavy canvas cloth to hold the pitch. The specimens were polished for about ten hours on this. Massive chromite which was mounted in one of the briquettes did not polish, but Figures 16 and 17 show the results obtained with the other two. Lubrication was with water. Oil cannot be used on a pitch lap because it dissolves the pitch. Oil was not tried when grinding on the cast-iron lap, but would probably be a good lubricant to use.

Third Method

Due to the long time taken by the method just outlined, it was decided to try again the first method under a slightly different set of conditions. The holes in the plate were drilled perfectly perpendicular to its face this time, and constant volume briquettes were prepared. This was done by measuring the volume of the specimen by displacement, and calculating the amount of bakelite or lucite necessary to make a sixteen c.c. briquette (approximately one-half inch thick). The amount of bakelite or lucite necessary is equal to sixteen minus the volume of the specimen, times the specific gravity of the bakelite or lucite.

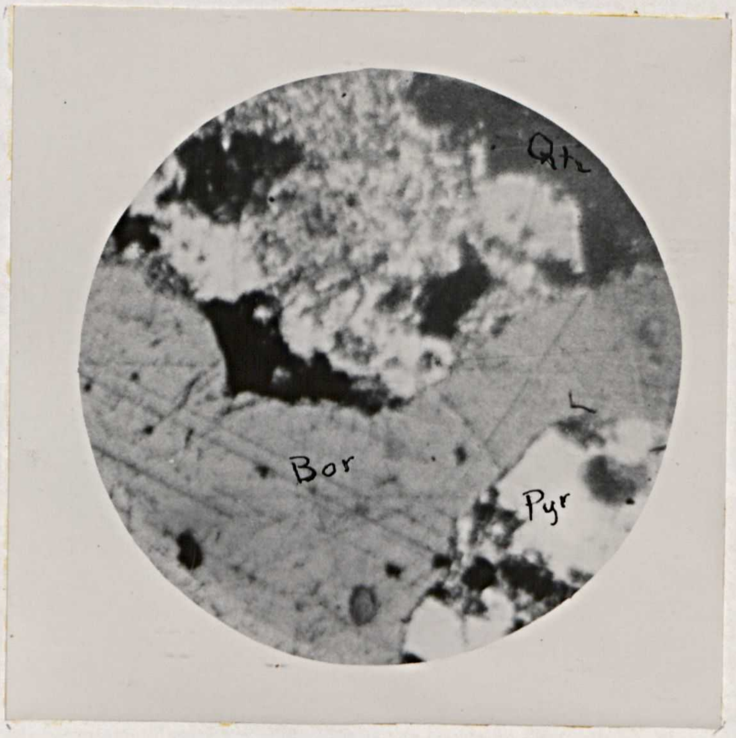
The threads in the bakelite briquettes were crumbly, and would not hold onto the screws, because minus one-hundred mesh bakelite was used, and this size of material crumbles much worse than the coarser material.

Figure 16



Hematite and Quartz

Figure 17



Bornite, Pyrite, and Quartz

since the briquettes were all of the same thickness, and could be held flush against the specimen holder, they did not have to be held tightly. Those whose threads crumbled were therefore loose and revolved around the projecting bolts. After grinding for eight hours and polishing for three hours most of the specimens were seen to take no polish at all, while two of them that did appear to be polished to the naked eye were seen to be extremely pitted and scratched when examined under the microscope.

DISCUSSION OF RESULTS

First Method

It can be seen from the photomicrographs that in the first method used the harder minerals took a better polish than the softer ones, being much freer of pits and scratches. The probable reason for this is that the coarse abrasive used in obtaining a level surface scratched and gouged the softer minerals much more severely than the harder ones. These abrasives may have caused subsurface shattering, already discussed on page 2, and thus have caused the pits. Further, the abrasive may have cut so deeply that the subsequent grinding did not remove these initial pits and scratches. The presence of dirt due to insufficient cleaning between each operation may also have caused these defects.

There are several disadvantages of not having the faces of the specimens in a level plane. One disadvantage is the additional time necessary to obtain a level surface. Another is the fact that the specimens are extremely scratched and pitted during this operation, and require additional fine grinding to remove these defects, which in the case of the softer minerals are never entirely removed within practical time limits. Another is the fact that if the threads are not well formed the specimens may get loose and work out of the same plane with the rest of the specimens. This would probably prevent the specimens from ever lining up in a plane again in which case polishing would be impossible.

It has been mentioned that the specimens were ground, polished, and then reground on a pitch lap. Discounting the time taken for this first polishing, because its effects were destroyed by regrinding, and also the two hours of final polishing with rouge, since it produced no noticable change in the polish obtained by alumina, it can be said that it took approximately 16 1/2 hours to grind and polish the specimens. This appears to be an exceedingly long time, but the hubnerite, and one or two of the other specimens, show a better polish than that which can be obtained on a Graton-Vanderwilt machine.

Second Method

The polish obtained by this method required about fifteen hours, and even this amount of time did not produce a polish on one of the specimens. The reason for the long time taken is probably that the time of grinding was too short, and the fine polishing alumina was really doing the work that should have been done by coarser abrasives. The jump from No. 600 alundum to minus 2.5 micron alundum in grinding was probably too great. An intermediate size of abrasive in this stage might have taken care of some of the coarse abrasion, and thus reduced the time of final polishing. The fact that the harder chromite did not polish seems to support this belief. The results obtained were good, and many of the mechanical difficultys encountered in the first method were eliminated. The hematite was the same as the hematite polished in the first method, and the results are seen to be about the same.

Third Method

One of the specimens used in this operation was extremely friable, and had plucked considerably. Since the method used was similar to that used initially, with most of the mechanical difficultys eliminated, it appears that these plucked out particles were the only thing which could have caused the scratching and pitting of the specimens.

CONCLUSIONS

Since the results obtained from the first and second methods used were very good, and a few of the minerals showed a better polish than is obtainable on a Graton-Vanderwilt type of machine, it appears that the method can certainly be used to advantage on certain types of minerals which will not polish on a Graton-Vanderwilt machine. The method has another advantage over a Graton-Vanderwilt type of machine in that its operation is very simple, and requires no special skill. Under proper conditions of properly graded size of abrasives, freedom from dirt and foreign material, and impregnating friable specimens with bakelite, the time of grinding and polishing should be reduced to compare favorably with that required on a Graton-Vanderwilt machine. If the method were adopted on a large scale it would be advisable to simplify the machine by eliminating the elliptical pulley and shortening the dimensions.

It would not have to be so large because the stroke used in polishing minerals is not nearly so long as that used in optical polishing. The machine could probably be reduced to one-half of its present size for large scale application.

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